Indian J. Phys. **67B** (5), 385 – 394 (1993)

Scintillation observation over Guwahati and computation with existing model

M K Barman, M Devi and A K Barbara
Department of Physics, Gauhati University, Guwahati-781 014 Assam, India

Received 23 April 1993, accepted 11 June 1993

Abstract : From a relatively long series of ionospheric scintillation study through VHF RB over Guwahati sample years (1980/81, 1989) are selected for computing scintillation index (SI). The SI are computed by using background density and its fluctuations received through *in situ* measurements as well as with ground based observations. The paper discusses results received through the model computation and from experimental observation and suggests that ground based N may be used for realising SI if $\Delta N/N$ parameter from *in situ* measurements is available

Keywords : Scintillation, ionospheric electron content

PACS No. : 94.20. Vv

1. Introduction

Ionospheric irregularities that generate scintillation at equatorial place are well known phenomena. Around the equator, an equatorial scintillation belt exists where the intensity of scintillation is even stronger than in auroral zones. Low or mid-latitude ionosphere is not excluded from these phenomena. Ionospheric scintillation differs widely with solar activity and at different geomagnetic situations. Latitudinal, longitudinal control on scintillation are also widely reported. In an effort to examine the causative mechanism of formation of these equatorial irregularities, a variety of ground based and *in situ* techniques have been employed [1-3].

Available data indicate differences in the characteristics of scintillations obtained from stations separated even by a narrow latitude and longitude zone [4]. Utilization of data from one communication channel, at another station becomes therefore questionable. Practically, it is impossible to construct a unified model which will describe all situations occurring in the real ionosphere. Nevertheless, any model should at least attempt to provide representation of the properties of the real ionosphere as accurately as possible for a given set of conditions. Modelling helps in understanding the ionospheric physics.

2. Observation

Radio Beacon signal at 136 MHz from the Japanese satellite ETS II was received at Guwahati (26.1°N, 91 47°E) for the last one decade and from the fluctuation of the recorded amplitudes of the signal (after defining fluctuations in terms of SI as per Whitney chart [5]) percentage occurrence of scintillation is calculated During 1980-1986 period, scintillation occurrence was high during summer months compared to other months However, it is interesting to note that the occurrence of scintillation was high during winter and some equinoctial months in the year 1989-1990

From these periods, the observations of the years *i.e.* 1980/81 and 1989 are selected as sample years for model computation (considering the complete differences in the seasonal occurrence pattern) of scintillation index The scintillation indices are grouped at intervals of ten in percentage and corresponding events are noted, for each case The occurrence of scintillation index of different depths (*i e* in the classified group) is then plotted for two seasons *i e* for winter of 1980 and 1989 period and summer of 1981 and 1989 (Figure 1 and Figure 2) It is apparent from the graphs that during summer of 1981, average occurrence of

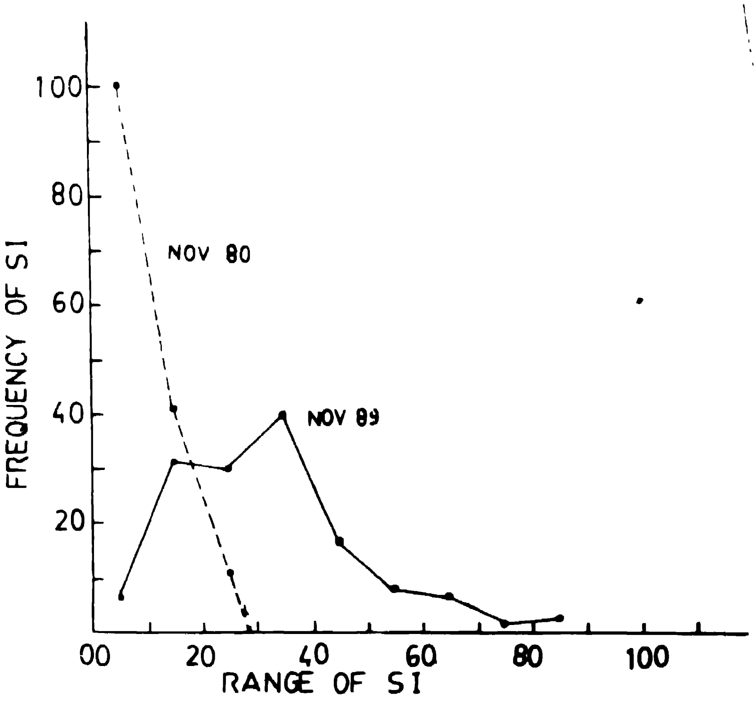

Figure 1. Occurrence of scintillation index of different depth for winter month

scintillation as well as depth of scintillation is higher than the average occurrence of scintillation (also depth of fading) in each group for the same season of 1989. Highest limit of scintillation index in the former case is 6 dB but for the latter it is 3.68 dB. For winter season of the respective years, observations are quite different The scintillation indices abruptly fall down to zero within 2.69 dB for November 1980 and on the otherhand scintillation index > 2.6 dB is abundant during the same month of 1989

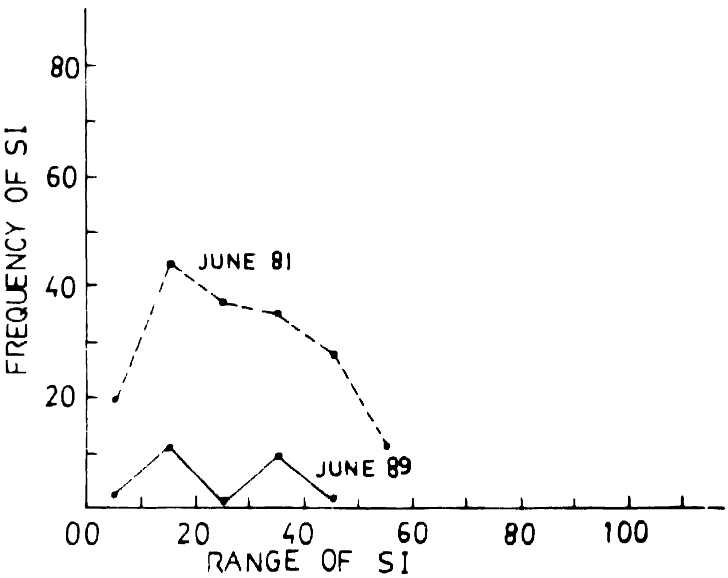

Figure 2. Occurrence of scintillation index of different depth for summer month

3. Model

The irregular plasma structure in the scattering medium imposes a random phase on the incident plane wave and that produces an interference pattern as the wave travels away from the irregular layer. This interference pattern is always observed at a single fixed point on the observer's plane Scintillation index follows a power law *i.e.* f^{-n} where value of n will be 0.1 to 0.2 But negative value of n is not impossible. Using the spectral approach with phase screen approximation these equations have been used to convert experimentally observed electron density fluctuations [6] to an equivalent diffraction theory based on S_4 index [7,8] It is noteworthy that scintillations are more sensitive to irregularities of sizes of the order of Fresnel dimension [7,9] which is approximately 1 km at the VHF For estimating fluctuations at very high frequency from *in situ* measurements, a spectral shape for the irregularities must be assumed In the regime for which the irregularity wave number $K_i >> K_0$, the outer scale wave number, the three dimensional power spectral density can be defined as $P_N(K_i) \propto K_i^{-p}$, p being the spectral index Spectral analyses of the high resolution data as well as other *in situ* measurements (like from OGO 6) have shown that the one dimensional irregularity power spectrum follows a power law with an index of approximately 2, over irregularity scale size ranges from tens of metres to tens of km [10,11] This spectral index is found to be insensitive to irregularity amplitude of the above range [12]. In keeping with this experimental finding, we adopt a three dimensional power law irregularity spectrum with spectral index $p = 4$.

S_4 index is nothing but second central moment of received radio wave intensity and is widely used to relate experimental scintillation measurement to irregularity parameters. The equations presented by Rufenach [12] are as follows

$$S_4 = 2^{1/2} \phi F f(\beta) \tag{1}$$

$$\phi = \frac{n^{1/2} (re\lambda)\, \Delta N\, (Le\alpha)\, (\sec \chi)^{1/2}}{2^{1/4}\, (\beta k_0)^{1/2}} \tag{2}$$

$$F = \left[1 - \exp\left(- \frac{\lambda Z}{2\pi k_0^2} \right) \right]^{1/2} \tag{3}$$

$$f(\beta) = \frac{\left(3\beta^4 + 2\beta^2 + 3\right)}{2.2^{1/2}\, \beta^2} \tag{4}$$

where, ϕ = phase fluctuation,

F = filter function,

r_e = classical radius of electron,

α = axial ratio of irregularity,

β = function of axial ratio and angle, between the ray path and magnetic field,

χ = Zenith angle,

k_0 = outer scale wave number,

ΔN = electron density fluctuation.

In these computations a mean height of 350 km of the irregularity layer which is the value of Z is used in the calculation of S_4. Eq. (1) clearly indicates that for different values of χ, α, Le, K_0 and ΔN, scintillation index may bear different magnitude

4. Calculation

For calculating scintillation index, realistic value of ΔN at that ionospheric height (near F peak) is essential. As one can not have this value from the ground based observation, *in situ* data if available for that period would be ideal. In the absence of that, we have adopted the following approach for determination of ΔN parameter. We would here realise the ionospheric situation for development of observed noctural winter scintillation for 1989 and 1980 The Zenith angle would be confined within 44° to 80° and 3° to 79° Irregularity size would be varying from isotropic to thin elongated structures. As a first approach, density fluctuation is taken from $\Delta N/N$ ratio from the reported data [6] from OGO 6 observation when it passes over this station during November. Using the value of N also from this reported data, ΔN is calculated and is found to be 8×10^8 elm^{-3}. As N (and hence ΔN) is dependent on solar activity, effect of it should be taken into account. For this purpose, ionisation density variation characteristics with solar activity as reported by earlier workeres over this station have been incorporated. The dependence of IEC (received through RB) with solar activity has been studied over this latitude covering a period from 1975 to 1982 [13,14]. Further, analysis of ionisation density received through ground based ionosonde with solar activity has also been made for a long period from 1964 to 1975 [15]. From these observations and results, we note that there should be an increment of the order of 10% over the OGO observation (taken on 1969) on ΔN for the solar activity condition of 1989. Thus the modified value of electron density fluctuation is 8.8×10^8 elm^{-3} (*i.e.* of the order of 10^9 elm^{-3} for 1989)

Now, using values of χ, α, Le and K_0 suitable for F–height irregularities, S_4 is calculated. The S_4 parameters so received are shown in the Tables 1 and 2.

Table 1. Variation of S_4 with different values of, $K_0 = 0.251$ km^{-1}, $r_0 = 25$, $Le = 250$ km, $\Delta N = 10^9$ elm^{-3}, average $\chi = 52°$

α	F	$f(\beta)$	ϕ	S_4
1	0.08735	0.8660	0.36798	0.039
2	0.08735	0.7355	0.41665	0.037
3	0.08735	0.6650	0.2925	0.035
5	0.08735	0.6321	0.4369	0.034
10	0.08735	0.6185	0.4403	0.0336
15	0.08735	0.6161	0.4409	0.0335
20	0.08735	0.6152	0.4412	0.03353

From above table it is clear that when α increases from 1 to 20, the rate of decrease of $f(\beta)$ is higher than the rate of increase of ϕ. Therefore, net effect of increasing the value of α is to decrease the value of S_4

Table 2(a). Variation of S_4 with density fluctuation $K_0 = 0.251$ km^{-1}, $r_0 = 25$ km, $Le = 250$ km and $F = 0.08735$

α	$f(\beta)$	ΔN	ϕ	S_4
1	0.8660	10^9	0.36798	0.03936
		*2×10^9	0.73596	0.07873
2	0.7355	10^9	0.41665	0.03785
		*2×10^9	0.8333	0.07571
3	0.6650	10^9	0.42925	0.03526
		*2×10^9	0.8585	0.07052

* In case ΔN changes twice (arbitrary assumption)

Table 2(b). $K_0 = 0.157\ \mathrm{km}^{-1}$, $r_0 = 40$ km, $Le = 250$ km and $F = 0.055491$

α	$f(\beta)$	ΔN	ϕ	S_4
1	0.8660	10^9	0.4652	0.03129
		$^*2\times 10^9$	0.9304	0.06258
2	0.7355	10^9	0.5267	0.03009
		$^*2\times 10^9$	1.053	0.06018
3	0.6669	10^9	0.54274	0.02810
		$^*2\times 10^9$	1.0854	0.05620

* In case ΔN changes twice (arbitary value)

Table 3. Variation of scintillation index with Zenith angle (χ) (during midday and post sunset) $F = 0.08735$, $f(\beta) = 0.8660$, $\Delta N = 10^9\ \mathrm{elm}^{-3}$

Month	$(\sec\chi)^{1/2}$	ϕ	S_4
June	1.00	0.289	0.0309
	1.65	0.479	0.05113
July	1.00	0.289	0.0309
	1.65	0.478	0.05113
November	1.18	0.341	0.0365
	2.30	0.6647	0.07127

Tables 2(a) and 2(b) show that among all those parameters ΔN is the most sensitive factor that controls the scintillation index. In fact, similar observation has been reported by earlier workers too [16,17]. When ΔN increases twice, scintillation index automatically becomes double of its earlier value even for different irregularity structures.

It is noted from above, that the calculated scintillation indices through ΔN and N taken from *in situ* OGO 6 measurements (modified to appropriate solar situation) have never been approached the observed scintillation indices over this latitude for 1989, for all realistic irregularity parameters and both for thick and thin slab structures [18].

Failing in realising the ionospheric situation prevailing at F–height for generating observed scintillation at our latitude by using N value from *in situ* measurement, we re-examine the significant parameter like density fluctuation (that controls the scintillation more effectively) from ground based observation. For that purpose, the ground based ionosonde data at Guwahati available to us during the period OGO 6 had crossed our latitude, been consulted. This ionosonde was operated at every half an hour with the peak power of 10 KW. From the ionogram data of this station, the value of N is calculated out at 350 km height (as OGO measured irregularities at 350 km height) and this value is found to be 4.5×10^{11} elm^{-3} which is nearly 4.5 times higher than observed through *in situ* measurement. Now, taking the ratio $\Delta N/N$ as detected by OGO probe over our latitude, we calculate the modified ΔN parameter through background density received from bottomside probing of ionosphere over Guwahati The ΔN values observed are as follows

OGO 6 (1969)	Bottomside probing (1969)
8×10^8 elm $^{-3}$	3.55×10^9 elm $^{-3}$

The value of ΔN then normalised for solar activity situation of 1989 and ΔN (1989) turns out to be 4×10^9 elm^{-3}.

Keeping all the parameters as Table 2(a), calculated S_4 values are shown in the table as follows (during post-sunrise, mid-day and post-sunset)

$(\sec \chi)^{1/2}$	ϕ	S_4^*	S_4^{**}
1 80	1 825	0 200	0 0557
1 00	1 0139	0 1084	0 0309
2 30	2 332	0 2494	0.07126

Where S_4^* is the calculated scintillation index using N (therefore ΔN value) obtained from ground based ionosonde data over Guwahati during 1969 S_4^{**} represents the calculated scintillation index using N parameters from OGO probe over this latitude during the same period

Timing	$(\sec \chi)^{1/2}$	ϕ	S_4 calculated	S_4 observed (typical)
Post sunrise	1 80	2 085	0 2231	0 50
Noon	1 00	1 1588	0 1239	0 27
Post sunset	2 30	2 6652	0 2850	0 70*

It is seen that SI calculated by using N values from ground based ionosonde over Guwahati, is much higher than those received by using N values from OGO 6. The above table summarises the calculated (with ground based N value) and observed SI values at different hours of the day. The result is encouraging except for the post sunset period.

5. Discussion

We have observed from the study that scintillation is largely dependent on the density variation (deviation) as well as on the background density of the medium. The presence of significant association of density deviation towards scintillation has been reported by earlier workers too [19]. We have observed that the ΔN as measured through RPA probe over our latitude can generate a situation when scintillation would hardly be detected over our place. But on using background density (almost at the same probing height of the OGO 6), through bottomside sensing of the ionosphere over Guwahati for the same period, we receive a relatively higher ΔN value which while used for SI calculation, gives more realistic scintillation parameter appropriate for that solar activity situation. Moreover, when the modified ΔN values are normalised for 1989 solar condition, we could realise almost all the observed winter night (even many daytime) scintillation events of 1989. The SI values

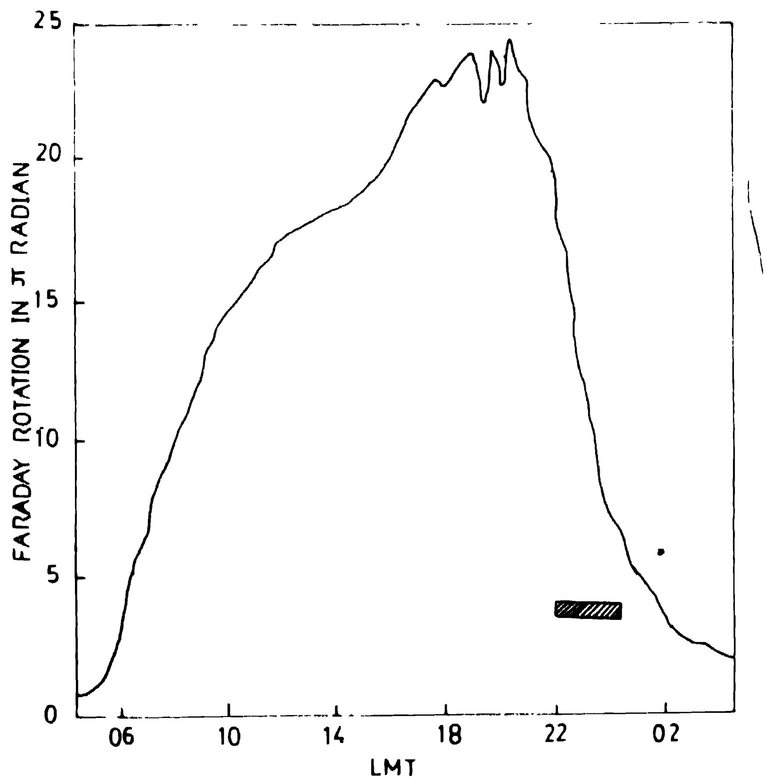

Figure 3. Faraday rotation Plot (—) shows TEC behaviour (on 9 November, 1981) observed with amplitude scintillation ( )

calculated through RPA data (ΔN modified for 1989 solar situation) are far lower than the observed values for all winter night-time events. This could probably be due to small duration data computation (*i.e.* for 4.7 sec). We have also noted that the post sunset SI values are much higher than those calculated through our modified ΔN value. One of the possibilities is the changes of background density because of development of PAE, which can extend beyond ± 15° geomagnetic latitude during high solar activity period. Our observation through

VHF RB [13,14] (also with ground based ionosonde) detects enhancement of background density during equinoctial and early winter (November) pre-midnight periods during high solar activity situation.

Figures 3 and 4 shows a few cases when enhancement of post-sunset IEC is seen along with development of scintillation during high solar activity period This large background ionisations have to be taken into account for explaining the large post-sunset indices*. Table shows calculated SI values with PAE effect and without PAE effect and it is seen that the post-sunset large SI could possibly be explained with the modulation of background density because of the PAE

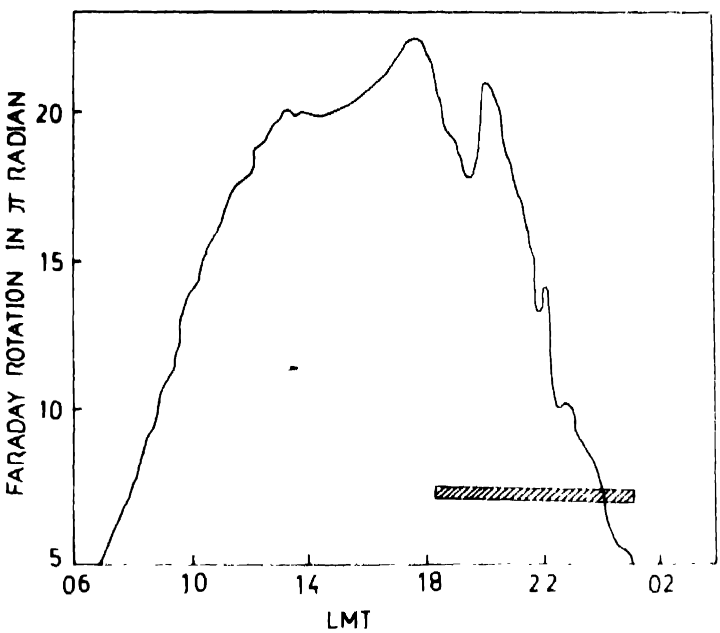

Figure 4. Amplitude scintillation patch ( ) observed (on 5 Nov'81) along with IEC behaviour (———)

S_4 observed	S_4 PAE not taken	S_4 PAE taken
0 7	0 4	0 7

So, finally it may be stated that once the $\Delta N/N$ ratio through *in situ* probe could be known, then SI at any other solar activity situation may be calculated if background density is known, even from bottomside observation.

Acknowledgment

The authors acknowledge with thanks the Council of Scientific & Industrial Research for their support for carrying out the work.

References

[1] D T Farley, B B Balsley, R F Woodman and J P Mc Clure 1970 *J. Geophys. Res.* **75** 7199

[2] J P Mc Clure and R F Woodman 1972 *J. Geophys. Res.* **77** 5617

[3] M C Kelley and F S Mozer 1972 *J. Geophys. Res.* **77** 4183

[4] J Aarons 1976 *IEEE Trans Antennas Propagat.* AP-24

[5] H E Whitney, J Aarons, R S Allen and D R Seeman 1973 *J. Atmos. Terr. Phys.* **35** 12

[6] S Basu, S Basu and B K Khan 1976 *Radio Science* **11** 821

[7] B H Briggs and I A Parkin 1963 *J. Atmos. Terr. Phys.* **25** 339

[8] C L Rino 1982 *Radio Science* **17** 855

[9] J A Ratcliffe 1956 *Rep. Prog. Phys.* 188

[10] P L Dyson, J P Mc Clure and W B Hanson 1974 *J. Geophys. Res.* **79** 1495

[11] R C Sagalyn, M Smiddy and M Ahmed 1974 *J. Geophys. Res.* **79** 4252

[12] C L Rufenach 1974 *J. Geophys. Res.* **79** 1562

[13] P Bardoloi 1984 *PhD Thesis* (University of Gauhati, Assam, India)

[14] K Rahman 1987 *PhD Thesis* (University of Gauhati, Assam, India)

[15] P H Talukdar 1981 *PhD Thesis* (University of Gauhati, Assam, India)

[16] J Aarons and A Das Gupta 1984 *Radio Science* **19** 731

[17] S Basu, E Mac Kenzie and S Basu 1988 *Radio Science* **23** 363

[18] H Kumagai 1987 *Radio Science* **22** 439

[19] J Aarons, H E Whitney, E M Kenzie and Santimay Basu 1981 *Radio Science* **16** 939